LAPTH-Conf-990/03
hep-ph/0307304
July 24, 2003

COMOVER ENHANCEMENT SCENARIO FOR QUARKONIUM PRODUCTION*

S. Peigné
LAPTH, B.P. 110, F-74941 Annecy-le-Vieux Cedex, France
E-mail: peigne@lapp.in2p3.fr

The quarkonium data suggest a qualitatively new production mechanism, enhancing the rate of the quarkonia produced in the fragmentation region of an incoming coloured particle.

1 Introduction and summary

The production of heavy $Q\bar{Q}$ quarkonia is a promising probe of QCD dynamics, both in its perturbative and non-perturbative aspects. However, in quarkonium production even a qualitative agreement between theory and experiment is not yet achieved. In such a situation, it might be useful to recall the qualitative features of the quarkonium data, in order to gain some possibly new insight.

In this talk I argue that the main features of the quarkonium production data suggest a new mechanism for quarkonium low $p_\perp$ hadroproduction, which breaks factorization between the perturbative production of the heavy $Q\bar{Q}$ pair and its subsequent hadronization into a bound state. The mechanism is based on the rescattering of the $Q\bar{Q}$ pair on the comoving field created in gg fusion, and appears to be qualitatively consistent with many features of the quarkonium production data. We expect a similar mechanism to occur each time the $Q\bar{Q}$ pair is produced in the fragmentation region of a coloured particle, and thus surrounded by the DGLAP field radiated by this particle.

*To appear in the proceedings of the XIth International Workshop on Deep Inelastic Scattering, St. Petersburg, 23-27 April 2003.

2 The qualitative difference between hadro and photoproduction

The first well-known fact I would like to recall is the failure of the Color Singlet Model (CSM) in predicting quarkonium *hadroproduction* rates: J/ψ and ψ' hadroproduction rates are underestimated by more than an order of magnitude, both at low $p_\perp \lesssim m_c$ [1] and large $p_\perp \gg m_c$ (the ψ' anomaly) [2]. We stress however that at large $p_\perp$, the *shape* of $d\sigma(p\bar{p} \to \psi + X)/dp_\perp$ is correctly given by the perturbative part of the process, which is dominated by gluon fragmentation [3]. Even though the fragmentation channel appears beyond leading-order (LO) in the CSM, *the CSM predicts correctly the shape of* $d\sigma/dp_\perp$, as does in fact any model where the $Q\bar{Q}$ pair is produced perturbatively.

In contradistinction with the clear failure of the CSM in ψ hadroproduction, the CSM works surprisingly well when the projectile hadron is replaced by a photon. Namely, *the CSM is consistent with quarkonium photoproduction.*

- In inelatic photoproduction, the CSM at NLO agrees well with the data, up to $p_\perp \simeq 7$ GeV $> m_c$ and for values of $z > 0.3$[1] [4, 5]. We note that the CSM LO process $\gamma g \to J/\psi g$ is clearly insufficient, since the dominant photoproduction channel at $p_\perp > m_c$, namely $\gamma g \to J/\psi gg$, appears at NLO.

- In DIS, the J/ψ production data from H1 have been compared to the CSM at LO [6]. The LO CSM underestimates the DIS J/ψ rate by a factor $K \sim 2 - 3$ (to be contrasted with $K > 10$ in hadroproduction), and does not yield the correct $p_\perp$-shape. The above reasonable 'K-factor' is likely to be explained by NLO contributions and, again, CSM at LO is insufficient since it misses the dominant channel at $p_\perp \gg m_c$. It is clear that NLO contributions will improve the CSM prediction, both in shape and normalization.

- In $\gamma\gamma$ collisions, the CSM has been recently shown to underestimate the J/ψ production rate (at $p_\perp \leq 3$ GeV) by one order of magnitude [7]. This may not be surprising, since the $\gamma\gamma \to J/\psi + X$ rate is actually dominated by single resolved photon processes [7], namely $\gamma g \to J/\psi + X$, and the measured rate is integrated over a J/ψ rapidity $-2 < y_{J/\psi} < 2$.

[1] The J/ψ rate thus arises from the photon fragmentation region, and resolved photon processes are negligible here.

The failure of the CSM in the present case might be due to an underestimation of the rate in the resolved photon fragmentation region, in which case it would be directly expected from the similar failure in low $p_\perp$ hadroproduction.

3 A new mechanism for quarkonium hadroproduction

We know that the CSM is not a consistent model for quarkonium production. In particular, contributions from the Color Octet Model (COM) are necessary to make inclusive P-wave decay rates infrared finite. On the other hand, the COM has several difficulties when confronted to the data. The COM prediction for ψ polarization at the Tevatron seems to disagree with the observation [8], and the COM tends to overestimate quarkonium photoproduction rates [2].

Our attitude is to suppose that the success of the CSM in photoproduction is not fortuitous, and suggests the presence of a new production mechanism, occurring in hadroproduction, and more generally when the $Q\bar{Q}$ pair is produced in the fragmentation region of a coloured particle participating to the hard $Q\bar{Q}$ creation process.

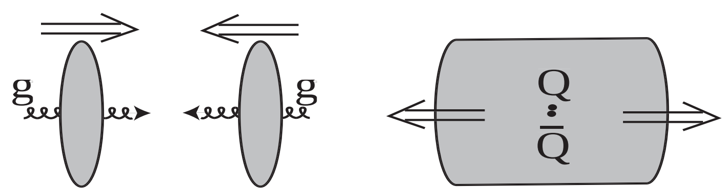

Figure 1: Quarkonium hadroproduction induced by the rescattering of the heavy $Q\bar{Q}$ pair off the surrounding DGLAP-originated color field.

At high energy, quarkonium hadroproduction is dominated by gg fusion, as pictured in Fig. 1. Each of the incoming gluons carries its proper bremsstrahlung DGLAP field, and the heavy $Q\bar{Q}$ pair is thus produced in a rich comoving environment, in any fragmentation region. In non-resolved photoproduction, this environment is absent in the photon fragmentation region (but should be present in the target hadron fragmentation region). Similarly, it will also

appear in $\gamma\gamma$ collisions, in the fragmentation region of the incoming photon which is resolved.

We have suggested that semi-hard rescatterings between the $Q\bar{Q}$ pair and this comoving field could explain the observed 'anomalies' of quarkonium production [9]. Qualitatively, this 'Comover Enhancement Scenario' (CES) allows to explain the discrepancy of the CSM with quarkonium hadroproduction and resolved photoproduction (or resolved $\gamma\gamma$ collisions). The scenario is consistent with the success of the CSM in the photon fragmentation region of (non-resolved) photoproduction.

In low $p_\perp$ hadroproduction, the comoving field is assumed to arise from the DGLAP evolution of the incoming gluons (Fig. 1). Since (at least) one rescattering between this field and the $Q\bar{Q}$ pair is used to create the quantum numbers of the bound state finally produced [9], our scenario breaks the factorization usually assumed between the $Q\bar{Q}$ pair production process and its subsequent color neutralization. This mechanism is thus not included in the COM expansion, although there is a priori no reason to neglect it.

Large $p_\perp \gg m_Q$ quarkonium hadroproduction is dominated by the fragmentation of a quasi-real gluon, $g(p_\perp) \to Q\bar{Q}$ [3]. Since interactions between the $Q\bar{Q}$ pair and the DGLAP fields of the incoming partons are suppressed by powers of $1/p_\perp$, it is tempting to generalize our low $p_\perp$ scenario to large $p_\perp$ production by considering the DGLAP field of the fragmenting gluon itself as a source of comovers. Any possible further rescattering with the $Q\bar{Q}$ pair respects factorization, but it is not clear whether this type of process is included in the COM. Little is known on the convergence of the COM expansion, and we cannot exclude that high orders in α_s and v are phenomenologically important, as suggested by the failure of the COM at first orders in predicting ψ polarization at large $p_\perp$.

We have shown that assuming the relevance of the Comover Enhancement Scenario (CES) and of the color singlet quarkonium wave function allows to explain many features of the quarkonium production data [9]. We summarize below the main successes of the CES and refer to Ref. [9] for more details.

- The CES leaves intact the success of the CSM in direct photon processes.
- Since the comoving field arises from DGLAP evolution, the CES is a leading-twist mechanism, consistent with the fact that the 'anomalies' of

quarkonium production subsist when $\sqrt{s}$, $p_\perp$, or m_Q are increased.

- The ratios of different S-wave quarkonium hadroproduction rates are consistent with the ratios of the (squared) color singlet wave functions at the origin.

- We expect the CES to enhance hadroproduction rates of $C = -1$ states and χ_1, which require three hard gluons to be produced. In this respect the fact that the CSM underestimates low $p_\perp$ χ_{c1} hadroproduction is not surprising.

- Qualitatively, the CSM is consistent with inelastic (and non-resolved) χ_{c1} and χ_{c2} photoproduction [10]. This will not be affected by the CES.

- Within the CES we expect quarkonium nuclear absorption in pA collisions to occur because of the absorption of the incoming DGLAP fields, resulting in a comoving field being attenuated compared to pp collisions. The CES thus suggests that nuclear absorption might be due to a *lack* of hard comovers, contrary to conventional explanations.

Acknowledgements

This talk is based on a collaboration with P. Hoyer and N. Marchal.

References

[1] D. M. Kaplan [E789 Collaboration], Int. J. Mod. Phys. A **12** (1997) 3827.

[2] See for instance M. Kramer, Prog. Part. Nucl. Phys. **47** (2001) 141.

[3] E. Braaten and T. C. Yuan, Phys. Rev. Lett. **71** (1993) 1673.

[4] C. Adloff *et al.* [H1 Collaboration], Eur. Phys. J. C **25** (2002) 25.

[5] S. Chekanov *et al.* [ZEUS Collaboration], Eur. Phys. J. C **27** (2003) 173.

[6] B. A. Kniehl, Nucl. Phys. Proc. Suppl. **116** (2003) 131.

[7] M. Klasen, Nucl. Phys. Proc. Suppl. **116** (2003) 141.

[8] E. Braaten, B. A. Kniehl and J. Lee, Phys. Rev. D **62** (2000) 094005.

[9] P. Hoyer and S. Peigné, Phys. Rev. D **59** (1999) 034011; P. Hoyer, N. Marchal and S. Peigné, Phys. Rev. D **62** (2000) 114001; P. Hoyer, N. Marchal and S. Peigné, hep-ph/0209365.

[10] P. Roudeau [NA14 Collaboration], Nucl. Phys. Proc. Suppl. **7B** (1989) 273.